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CONTENTS

ABSTRACT

A ballistic performance specification is to be prepared for the Naval Air Systems Command for use in connection with the procurement of Ceramic-GRP Composite Armor. Ballistic data from tests of alumina-GRP targets employing caliber 0.30 inch APM2 projectiles are provided. All ballistic tests were made with the missile trajectory normal to the target surface. Single impacts were made at the center of the ceramic tiles. For these test conditions, tentative conclusions are drawn as to the effect on penetration resistance of (a) purity of alumina, (b) type of GRP backing, (c) spall shields and (d) ratio of areal density of alumina to GRP.

PROBLEM STATUS

This is an interim report. Work on this problem is continuing.

AUTHORIZATION

NRL Problem F04-15
Project No. AIR-320-071/652-1/F020-01-01
NWL Code No. 27C
NASC Task Assignment AIR-320-010/291-1/F020-9-9

INTRODUCTION

A ballistic performance specification governing the acceptance testing of ceramic faced composite armor is being prepared by the Naval Weapons Laboratory under reference (a). The Naval Research Laboratory is, by request of the Naval Air Systems Command, collaborating with NWL in planning the experimental program and performing limited portions of the armor tests.

The results of ballistic tests to be performed upon various composite targets are to be used for the purposes of (1) making comparisons of the level of protection provided by different types of targets over a range of target areal densities; (2) providing a realistic basis for establishing ballistic tables to be used in a specification and; (3) providing guidance in determining the manner in which ballistic acceptance tests are to be performed and the number of tests necessary to insure armor quality to a specified confidence level.

The preliminary investigations along with other data available from the literature are being used to help determine the work necessary to generate information for preparation of the specification. This increment of work is being reported in order that the results may be readily available to others working with the same or comparable armor materials. It has been assumed that the report will be used by those familiar with terminology peculiar to the area of work. An effort has been made to include all information relative to target construction, etc. which might have an influence upon the target penetration resistance.

The conclusions are based upon limited ballistic data and therefore should be considered as tentative. However, there are sufficient quantities of data to indicate definite trends. These are of value in determining some factors which should be considered in the preparation of the specification and indicate areas where additional ballistic data are needed.

DISCUSSION OF MATERIALS AND TESTS

The specification for composite armor is to include ceramics backed by a glass fiber reinforced plastic. The specific ceramics are alumina, silicon carbide and boron carbide. The data reported here were obtained using alumina as the facing material for all targets.

The data presented were obtained through the coordinated efforts of the NRL and NWL. All ballistic limits are based on center tile impacts. The test procedures at these activities differ in the projectile used. NRL uses a caliber .30 APM2 projectile from service loaded ammunition while NWL uses the caliber .30 APM2 plate testing projectile. These projectiles differ only in that the plate testing projectile is manufactured to closer tolerances. The plate testing projectile was developed by Frankford Arsenal in 1941 in order to minimize one of the variables encountered in the evaluation of light armor. Further comparison of these projectiles along with results of correlation tests can be found in Table 1.

Targets used in these tests consisted of backing material to which one or two tiles were bonded, Fig. 1-a and b. Spall shields were used only as noted in Table 2. Spall shields were applied as shown in Fig. 1-c.

Total target areal density, as used in this report, is the sum of the areal densities of the ceramic facing and the glass reinforced plastic backing only. Weights of spall shields and material used to bond the ceramic to the backing are not included. The deletion of the areal density of spall shields and/or resins used for bonding the composites is desirable for purposes of comparing the performance of different composite armor. However, these weights are to be taken into account in the preparation of ballistic tables to be included in specifications where a required ballistic limit velocity is given for a specific areal density target. In addition to taking into account the weight added, it is necessary that the effects upon penetration resistance resulting from use of spall shields etc. be taken into account. Reference (b) and this report provide some information which show that the addition of certain spall shield materials result in a significant decrease in penetration resistance.

A variety of alumina-Doron targets were ballistically tested at NRL during 1964. The work included tests with caliber 0.30 inch APM2 projectiles striking the targets at normal incidence. Armor samples tested with the caliber 0.30 inch APM2 projectile included combinations of tiles of 94% , 95% , 99% and 99.3% pure alumina from two sources, backed with Doron from three manufacturers. These samples had areal densities (AD) ranging from 6.0 lb/ft^2 to 9.8 lb/ft^2. The data were uniform and reproducible with small ranges of mixed results. The effect of using different methods of bonding ceramic to the backing, target configuration and mounting, and varying the areal density ratio (i.e. ratio of facing AD to backing AD) in the range 1.4 to 3.3 were investigated. This range of areal density ratios bracketed most of the data which were available at that time. No spall shields were used on the targets. The results of these tests are plotted in Fig. 2. Two targets having a .030" alclad aluminum sheet on the front of the ceramic were impacted at just below the velocity necessary to penetrate similar targets without the aluminum. Neither target was penetrated, indicating that the aluminum did not decrease the penetration resistance of the composite significantly.

Testing during 1966 has extended the areal density range of alumina-Doron composite targets to 10.96 lb/ft^2 and also has included 85% alumina as facing material. As shown in Fig. 3, data obtained on targets composed of Doron backing with 85 to 99.3% alumina facing, except for two targets having an areal density ratio of 1.4, may be enclosed by a scatter band approximately 200 ft/sec wide over the range from 6.0 to 11 lb/ft^2. The 85% alumina appears to give ballistic limits as high as those obtained using the higher purity alumina. For nine ballistic limits on targets made from 85 percent alumina six exhibited a range of mixed results. For seven targets made from 95% alumina, mixed results were observed for two targets and for 99.3 percent alumina one of eight targets exhibited mixed results. Although the data are limited, this suggests that the results obtained from the ballistic evaluations of 85% alumina composite targets are not as sharply defined as for targets utilizing higher purity alumina. The range of mixed results influences the number of tests which must be performed in acceptance testing to provide assurance of a given quality of armor on a statistically significant basis. The NWL work planned, reference (c) , included the determination of probability of penetration versus impact velocity for targets produced from two grades of alumina. These data will establish the range of mixed results and provide information needed to specify the testing procedures and criteria to be used in the ballistic acceptance testing of these materials.

Targets provided by manufacturer D to NWL were tested at NWL and NRL to determine the effect of spall shield, backing material and areal density ratio on ballistic performance. The targets consisted of two 5.625 in. by 5.625 in. by 0.34 in., 85% pure, alumina tiles mounted on 12 in. by 12 in. bonded woven roving. The tiles were affixed with Pro-seal and covered with a polyurethane spall shield. The as-received targets had an areal density of 10.5 lb/ft^2 and an areal density ratio of 1.4. Tested at NWL, these targets had a V_p of 2974 fps. Identical targets tested at NRL had a V_p of 3056 fps. The difference in limit velocities determined at NWL and NRL is not unusual and may be attributed to the fact that NWL uses the plate testing projectile as opposed to the service projectile used at NRL (see Table 1). The limit velocity of these as received targets was somewhat lower than expected when compared to earlier data collected at NRL on targets made with Doron backing. The spall shield and low (1.4) areal density ratio were considered as possible contributors to this decrease in performance. NWL stripped several layers of woven roving backing from the targets to give a total areal density of 9.3 lb/ft^2 and an areal density ratio of 2.0 and determined a V_p of 2776 fps for these targets. This brought the performance closer to, but still slightly below, the NRL data obtained with Doron backing. The decrease in limit velocity due to stripping the targets was 200 fps less than would have been expected due to the reduced areal density. It appears that the 1.4 ratio is lower than is required for the most effective ballistic performance and that increasing the ratio to 2.0 improves the relative performance. This agrees with the indication that alumina-Doron targets with a ratio of 1.4 were less effective than targets with ratios of 1.8 or above (see Fig. 3).

Removing the polyurethane spall shield from the alumina resulted in a considerable increase in limit velocity for manufacturer D's targets tested at 10.5 and 9.3 lb/ft^2. NRL determined (Table 3 and Fig 4) that, without the spall shield, the 10.5 lb/ft^2 target had a V_p of 3362 fps and the 9.3 lb/ft^2 target had a V_p of 3012 fps. This is an increase of 10.4% and 8.5% respectively over the same targets with spall shields. This is in good agreement with results reported earlier by Goodyear Aerospace Corp., reference (b) that either polyurethane or ballistic nylon cloth spall shields reduced the ballistic limit of 8 lb/ft^2 alumina-bonded woven roving targets by about 9%. Apparently, the spall shield materials presently used will result in about a 10% decrease in the ballistic limit of these composite targets. Allowance must be made for this in establishing the specification for this type armor. Recent work reported in reference (d) indicates that the use of other spall shield materials does not result in as large a decrease in penetration resistance as the materials in current use. This was also indicated in reference (e).

Laminated bonded woven roving produced by three different manufacturers has been used as backing material. All of the roving laminates were bonded with a polyester resin and were similar to the type of laminate developed by Picatinny Arsenal for use in composite armor. Laminates were purchased from one manufacturer using a purchase description based on information furnished by Picatinny Arsenal. This was expected to result in a laminate which Picatinny had found to be a near optimum backing material. The manufacturer had previously produced laminates for Picatinny Arsenal. The materials used for production of the woven roving laminates are given in Table 4. As may be seen in Fig. 5, the data from the tests on targets using the woven roving materials backing lies, on the average, slightly above the data for targets using Doron as a backing. The data fall within a scatter band of approximately 200 ft/sec. If the mid point within this band is taken as the average level of protection and compared to similar values for Doron backed targets a difference of about 100 ft/sec is obtained. The limited tests on targets using woven roving laminates from three different sources does not provide a basis for distinguishing between them. A substantially larger amount of data would be required to show whether or not small but real differences in performance exist for the woven roving laminates from different manufacturers.

The data indicate that variations in performance of targets using woven roving as the backing materials is of about the same magnitude as for targets backed with Doron. For targets made from 85% alumina and either type backing, the data suggest that differences of about 200 ft/sec may be observed between two sets of apparently identical targets when ballistic limits are based upon a small number of tests. Although the above comments were made relative to the backing materials this should not be taken as an implication that the apparent variation in ballistic limit velocity is attributed to the backing material. The ballistic data to be obtained at NWL (see reference (c)), may provide information as to the target component which results in the observed variations. If a relatively large range of mixed results exist for a given type target, then a ballistic limit based on a few rounds may be expected to differ appreciably from the velocity which corresponds to the true fifty percent probability of penetration. The larger the range of mixed results, the greater will be this difference for a limited but fixed number of impact velocities used in computing the ballistic limit.

The woven roving laminates offer the following advantages over Doron for this application, (1) an increase in penetration resistance of the composite targets, (2) less delamination and bulging and (3), a cost advantage.

SUMMARY AND CONCLUSIONS

Although the numbers of targets used in these investigations were limited the study was fairly comprehensive in that several variables were considered. The alumina tiles were obtained from two sources. The purity of these tiles ranged from 85% to 99.5%. Two types of glass reinforced plastics from a total of five sources were tested as backing materials. Four different materials were used to bond the ceramic to the backing. In addition to variation in materials, two other effects were examined; (1) the effect of varying the areal density ratio, and (2) the effect of adding a spall shield. The following tentative conclusions have been drawn from the data listed in Table 1 and plotted in Figs. 2 through 5.

a. There are no apparent differences in the ballistic quality of tiles in the same purity range but from different sources.

b. There is little, if any, difference in the average ballistic quality of different purity alumina tiles in the range of purities considered. However, some of the data indicate an increase in the zone of mixed results when 85% alumina tile is used.

c. In the range of areal densities studied, results indicate the armor specimens with bonded woven roving backing gave slightly higher ballistic limits than those with Doron backing.

d. The ballistic limits for specimens with areal density ratio of 1.8 and above were all within a scatter band of about 200 ft/sec for each of the two types of GRP backing materials. When this ratio was reduced to 1.4, the ballistic limit dropped about 5% for targets weighing about 10 lbs/ft^2.

e. A polyurethane spall shield reduced the ballistic limit between [illegible]% and 10%. Results published in reference (b) indicate that the use of spall shields of ballistic nylon resulted in a similar deterioration of the ballistic limits.

f. Results of these tests indicated that resistance to penetration was not affected by different methods of securing the targets (mounting) for the ballistic tests.

(NOTE - Impacts at the center of the ceramic tiles result in ballistic limits which are maximum. In a service situation where impacts may occur near the borders of tiles or at seams between tiles, the ballistic limits may be lower than for impacts an appreciable distance from the borders or seams. Some data on the effect of impacts near seams are provided in Ref. (f). The development by manufacturers of techniques for production of larger (greater than approx. 6 x 6 inch) pieces of various ceramics has reduced the probability of having seam impacts thus reducing the importance of this factor. The "center of tile" impacts were used to give relative protection values with a minimum of material and testing. The effect of impacts at positions near the border of composite targets is in progress at NWL.)

REFERENCES

a NASC Task Assignment AIR 320 010/291-1/F0200101

b Composite Aircraft Armor Materials Research and Development, Fifth Quarterly Progress Report 21 June to 20 September 1965 Goodyear Aerospace Corp. (Conf.) 30 September 1965

c NWL letter report Serial No. 0661064 TEP-1: DWH:hwm 8960 of 12 August 1966 Conf.

d Picatinny Arsenal Letter Report of 16 August 1966 Fourteenth Report on Project 1P121401A150-03 (U) Secret

e NRL Memorandum Report 1541 Ballistic Evaluations of Composite Armor June 1964 Secret.

f Aberdeen Proving Ground Firing Record Ar-24858 of 18 January 1966 on USATECOM Project No. 4-4-1801-12 (Confidential).

TABLE 1. Comparison of Ballistic Limit Velocities Obtained With Caliber .30 APM2 Projectiles and Caliber .30 APM2 Plate Testing Projectiles

Targets	Activity Performing Tests	Projectile	V_p (1) ft/sec	V_p (2) ft/sec	R (3) ft/sec	RMR (4) ft/sec
CM-101(5)	(See Table 2) NWL	Caliber .30 APM2 Plate Testing	2974±34	2984	67	67
CM-73 (5)	(See Table 2) NRL	Caliber .30 APM2	3036±19	3041	65	38
2024-T4 Aluminum Alloy 1.00 in. thick	NRL	Caliber .30 APM2 Plate Testing	2241±47	2230 (6)	93	93
2024-T4 Aluminum Alloy 1.00 in. thk.	NRL	Caliber .30 APM2	2262±20	2256 (6)	40	40
Face Hardened Steel Aircraft Armor .270 in. thk.	NWL	Caliber .30 APM2 Plate Testing	2394±19	2392	46	0
Face Hardened Steel Aircraft Armor .270 in. thk.	NWL	Caliber .30 APM2	2451±30	----	--	--

1 V_p based on two rounds, highest incomplete and lowest complete penetration.

2 V_p based on four rounds, two highest incomplete and two lowest complete penetration.

3 Range of velocity covered by rounds used in computing ballistic limit based upon four rounds.

4 Range of mixed results for rounds used in computing ballistic limit based upon four rounds.

5 Identical composite targets of bonded fiber glass roving faced with alumina.

6 V_p based on ten rounds, five highest incomplete and five lowest complete penetration.

The following data were obtained from two groups of projectiles gaged at NRL:

	Hardness of Core Rockwell "C"	Projectile Weight grains	Core Weight grains
Plate Testing Projectile	63	167.5	87.2
Projectiles from Service Loaded Ammunition	60	162.6	86.6

Table 2 Alumina and Glass Reinforced Plastic Target Description

CM No.	Alumina % (c)	Alumina AD lbs/ft^2	Alumina Mfr. (d)	Backing AD lbs/ft^2	Backing Mfr. (d)	Backing Type	AD Ratio (e)	Bond (f)	Total AD lbs/ft^2 (g)	V_p ft/sec	Zone of mixed Results Ft/sec	CM No.
13(a)	94	5.70	A	2.89	C	Doron	2.0	R	8.59	2560±30		13
14	95	4.95	B	2.93	D	"	1.7	"	7.88	2340±25		14
15	95	3.95	"	2.20	C	"	1.8	"	6.15	1555±80		15
18	95	4.93	"	2.51	"	"	2.0	"	7.44	2247∓5	10	18
19	99.3	5.07	"	2.51	"	"	2.0	"	7.58	2205±30		19
20	95	4.95	"	2.51	"	"	2.0	S	7.44	2165∓5	10	20
22	95	6.83	"	3.02	"	"	2.3	T	9.85	3135±25		22
23	99.3	5.11	"	2.51	"	"	2.0	"	7.62	2270±25		23
26	99.3	5.15	"	3.65	"	"	1.4	"	8.80	2615±35		26
28	99.3	5.11	"	1.56	E	"	3.3	"	6.67	1755±15		28
52	94	5.68	A	3.12	D	"	1.8	R	8.80	2620±10		52
53	99	6.01	"	3.09	"	"	1.9	"	9.10	2865±15		53
62	85	5.45	A	2.98	F	Roving	1.8	U	8.43	2669∓14	28	62
63	85	5.53	"	2.81	E	Doron	2.0	U	8.34	2596±23		63
65	99.3	7.04	B	3.82	"	"	1.8	T	10.86	3446±40		65
66	99.3	7.04	"	3.06	F	Roving	2.3	"	10.10	3401±41		66
69	99.3	7.04	"	3.12	E	Doron	2.3	"	10.16	3322∓68	136	69
70	85	6.15	A	4.31	"	"	1.4	R	10.46	3141±15		70
71	95	6.79	B	3.40	C	"	2.0	"	10.19	3380±16		71
72	85	6.15	A	4.31	E	"	1.4	"	10.46	3266∓50	100	72
73	85	6.15	"	4.37	D	Roving	1.4	"	10.52	3036∓19 (h)	38	73
73*(b)	85	6.15	"	4.37	"	"	1.4	"	10.52	3362±34		73*
74	95	4.91	B	2.60	G	"	1.9	"	7.51	2440±40		74
75	99.3	5.09	"	2.60	"	"	2.0	"	7.69	<2342		75
76	85	6.15	A	3.12	D	"	2.0	"	9.27	3012∓27	54	76
101	85	6.15	A	4.37	"	"	1.4	"	10.52	2974∓34 (h)	68	101
102	85	6.15	"	3.15	"	"	2.0	"	9.30	2776∓26 (h)	52	102
103	94	5.76	"	4.1	E	Doron	1.4	"	9.86	2866±4		103

See next page for footnotes.

Table 2 - Continued

NOTES:

(a) Data for CM-13 through CM-53 from Ref.(e) CM numbers are laboratory numbers used for target identification. Ballistic tests of CM101, 102 and 103 were performed at the Naval Weapons Laboratory, all others were performed at the Naval Research Laboratory.
(b) Target No. CM 73* was the same as CM 73 except the spall shield was removed on CM 73* .
(c) Percent purity of alumina tiles.
(d) Letters A thru G indicate manufacturers or suppliers. (See Appendix A, published separately)
(e) Ratio of the areal density of facing to areal density of backing.
(f) Letters R thru U indicate type or trade names of material used to bond tiles to backing, i.e., R - Proseal #890, S - Epoxy, T - Double Backed Tape, U - Polyurethane.
(g) Total areal density of the target is the sum of the areal densities of the facing and backing only.
(h) Targets had a polyurethane spall shield. No other targets in this group had a spall shield.

TABLE 3: Effect of a Polyurethane Spall Shield on Ballistic Limit Velocity

NRL No.	Mfr.	Alumina Type	Alumina e	Alumina lbs/ft^2	Backing Type	Backing e	Backing lbs/ft^2	Ratio 1	Total Areal Density(2) lbs/ft^2	Activity Performing Tests	V_p ft/sec	Spall Shield
CM-101(3) CM-73 (3)	E	AD-85	.34	6.15	Bonded Roving	.4	4.37	1.4	10.52	NWL	2974	Yes
									10.52	NRL	3036	Yes
									10.52	NRL	3362	No
CM-102(4) CM-76 (4)	E	AD-85	.34	6.15	Bonded Roving		3.15	2.0	9.30	NWL	2776	Yes
									9.27	NRL	3012	No

(1) Ratio is Areal density of Ceramic divided by Areal density of backing.

(2) Areal density as given here includes the ceramic facing and backing material only. Spall shield if any and the resin bonding the ceramic and backing together are not included.

(3) CM-101 and CM-73 are identical targets.

(4) CM-102 and CM-76 are the same as CM-101 and CM-73 except that layers of the bonded roving backing were stripped from the later which resulted in a lower total areal density and a higher ratio.

Table 4 Materials used in Producing Woven Roving Laminates

Used for Targets Nos	Style Roving	Resin	Resin Content Percent by Weight (1)	Roving Cross-plied in Laminate
CM-73, 73, 76, 101, 102	Fiberglass Industries 2454/75	Naugatuck Chemical V156R	17.0-19.5	Yes
CM-62, 66	J. P. Stevens Style 1157 or equivalent	Rohm and Haas Paraplex P-43	31-33	No
CM-74, 75	J. P. Stevens Style 1157 or equivalent	Marco Chemical MR 28 R	26-27	No

(1) Determined at NRL in accordance with Method 7061. The resin contents reported were computed from weight lost by samples during burn out and have not been adjusted to reflect weight loss resulting from finish on the woven roving.

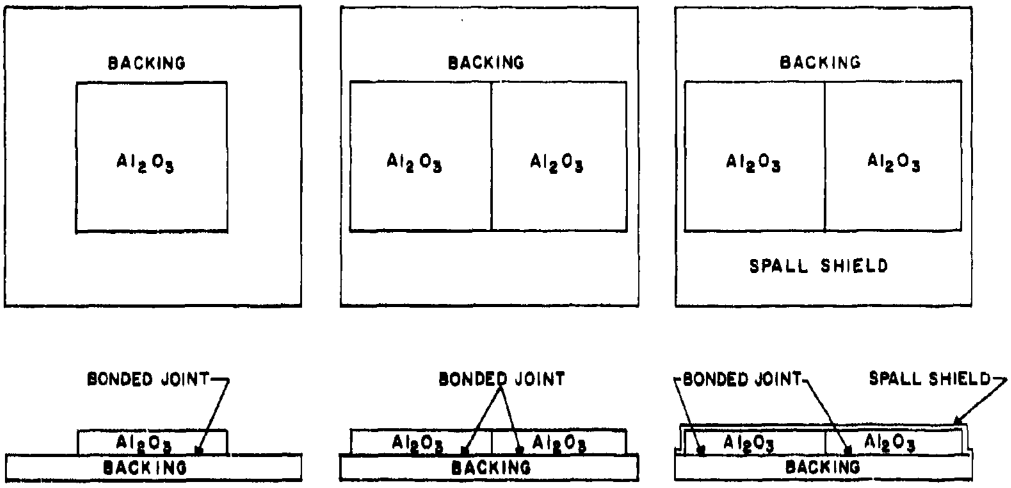

Fig. 1 - Target configurations

Target Coding (See Table 2)

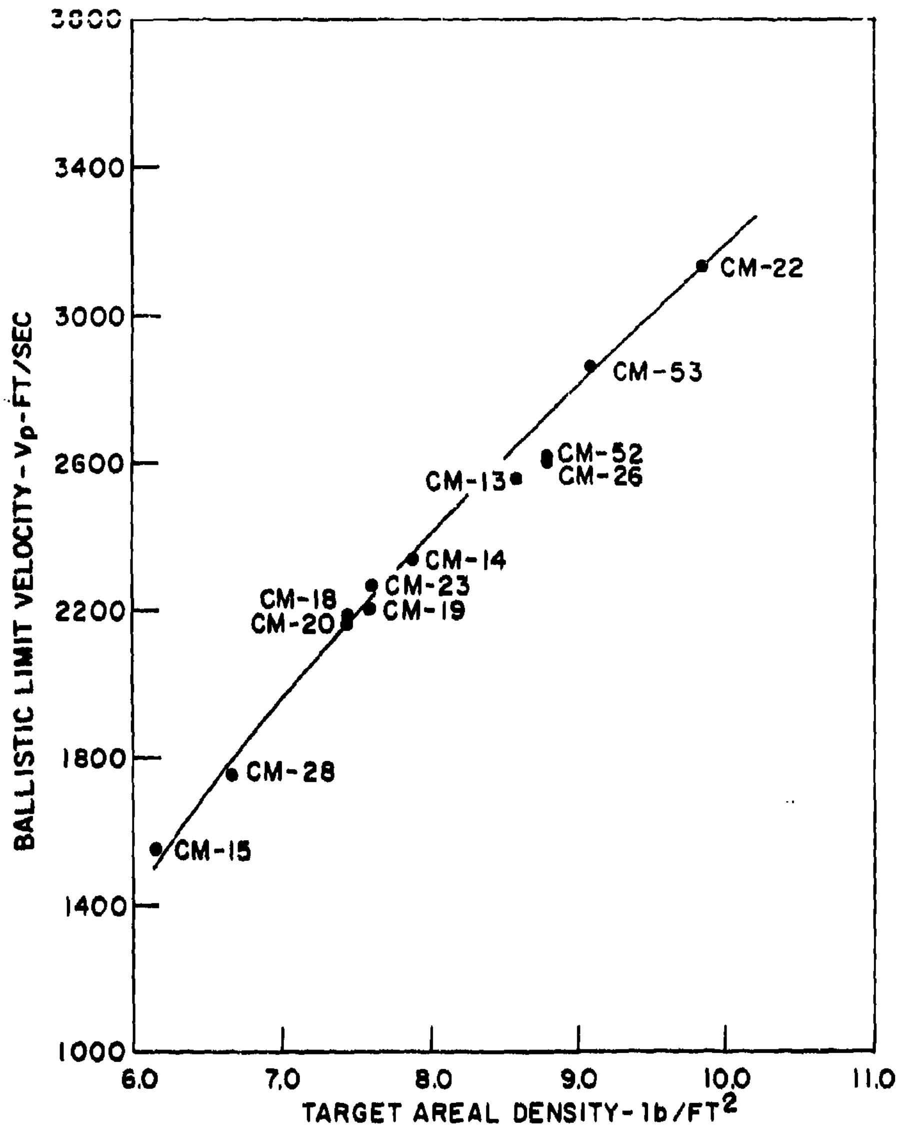

Fig. 2 - Alumina-Doron composite targets tested at NRL during 1964 with caliber 0.30 in. APM2 projectile. Targets vary in purity and source of alumina, backing mfr., bonding material, and mounting.

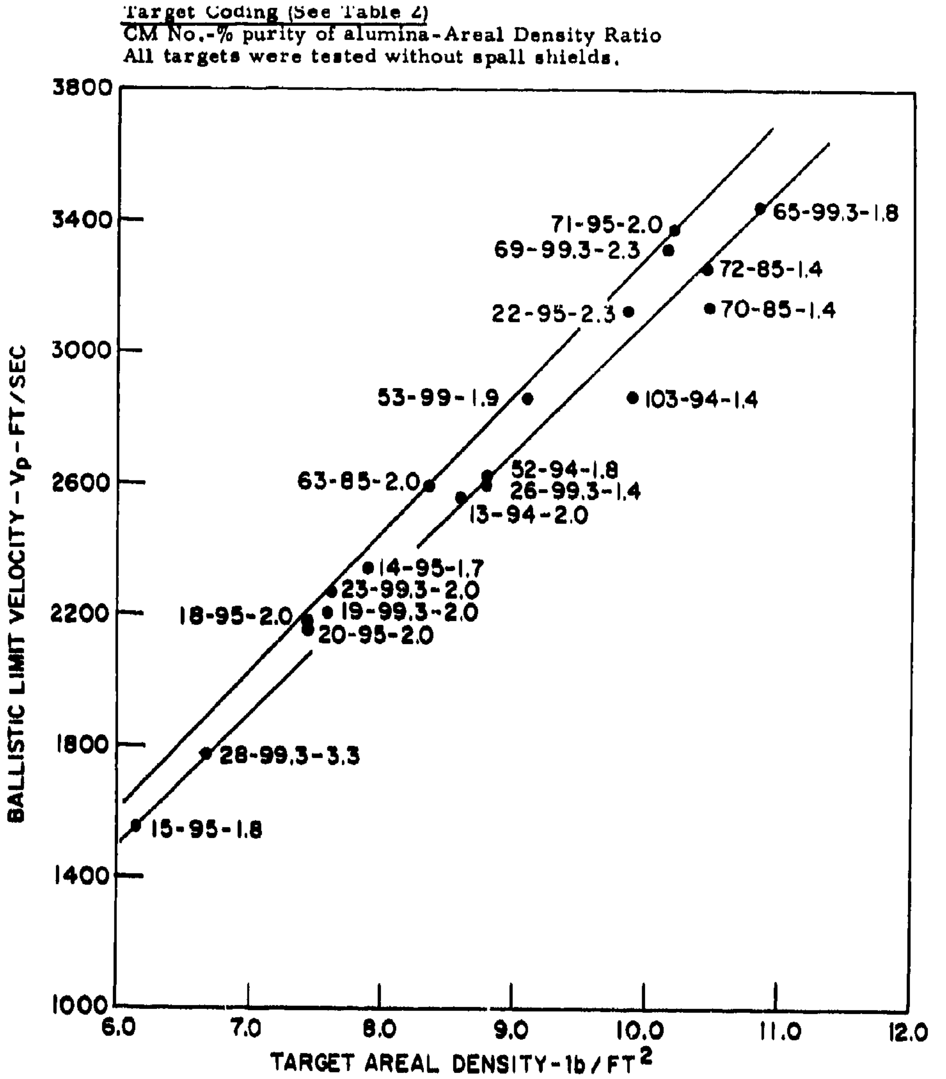

Fig. 3 - Effect of Al_2O_3 purity and areal density ratio on alumina-Doron composite targets tested with caliber 0.30 in. APM2 projectile

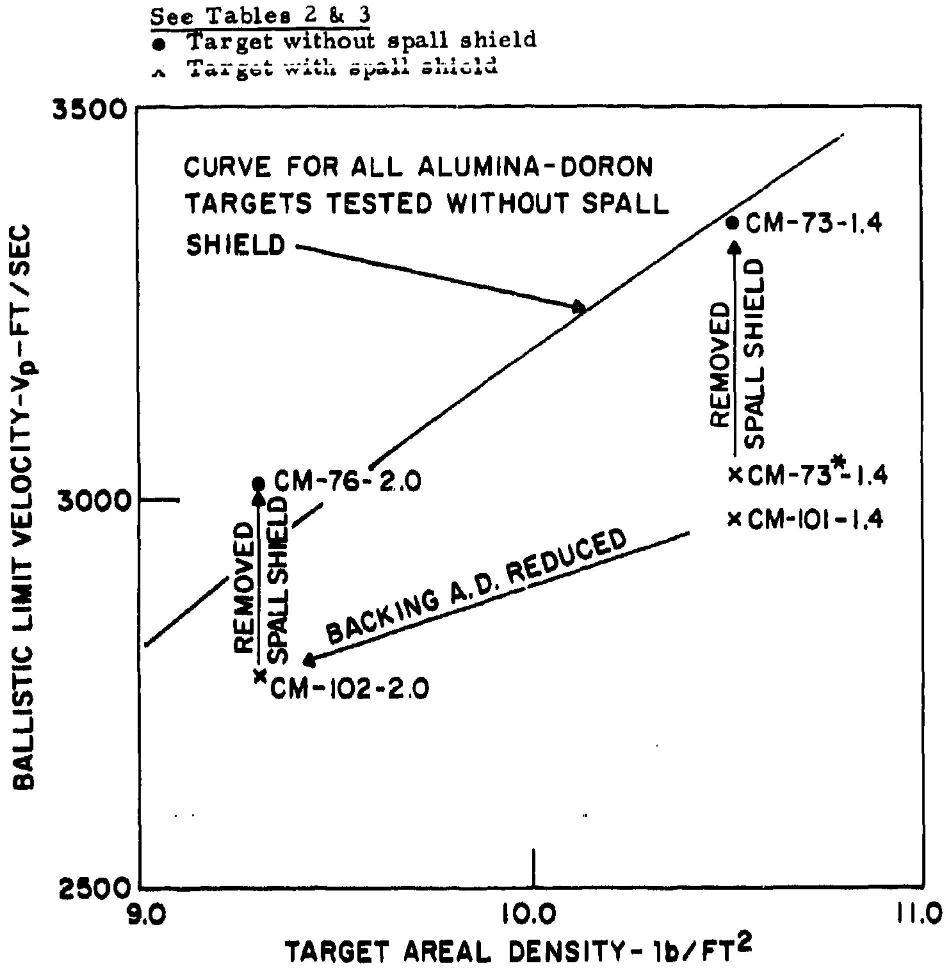

Fig. 4 - Effect of spall shield and areal density ratio on V_p of alumina-bonded woven roving composite targets tested with caliber 0.30 in. APM2 projectiles

See Table 2
All targets were tested without spall shields.

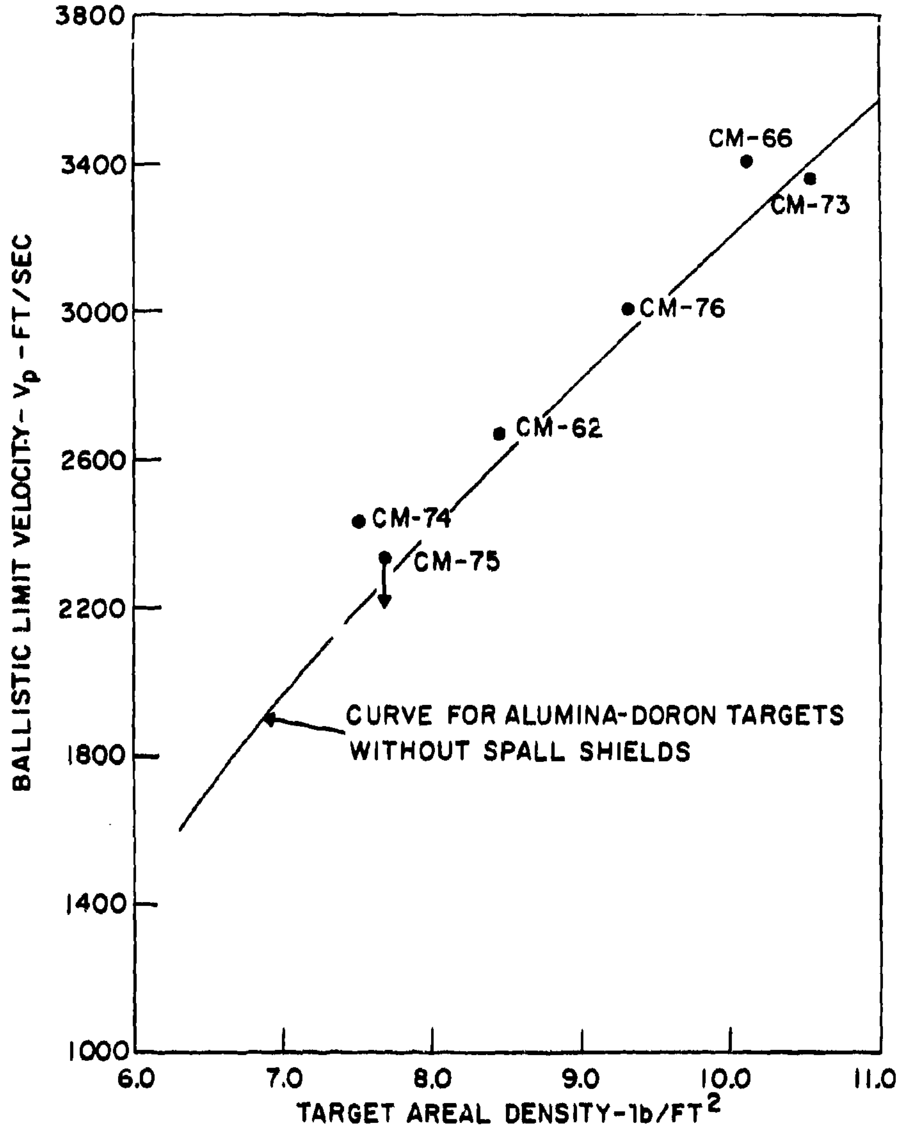

Fig. 5 - Alumina-bonded woven roving composite targets tested with caliber 0.30 in. APM2 projectiles

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